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EVALUATION OF CONVENTIONAL AND MODIFIED α-PARTICLE TRACK-ETCH SAMPLING HEADS IN RADON (THORON) PROGENY ATMOSPHERES

J. BIGU

ELLIOT LAKE LABORATORY

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by

J. Bigu*

ABSTRACT

Two α-particle sampling head designs have been evaluated in radon and thoron progeny atmospheres in a Radon/Thoron Test Facility. The sampling heads are part of an α-particle personal dosimeter using track-etch technology developed by CEA (France). A comparison was made between the performance of the conventional CEA track-etch sampling head and a modified version developed by the Canadian Institute of Radiation Safety (CAIRS). Under the experimental conditions of the tests, the agreement between the radiation exposure measured by the dosimeters and by grab-sampling techniques can be considered from poor to reasonably good, for radon progeny atmospheres. For thoron progeny atmospheres, significant disagreement was found between dosimetry and grab-sampling exposure determination. Quantitative differences in the response of the CAIRS sampling head and the CEA sampling head were found for thoron progeny atmospheres. The cause for the disagreement is arguably attributed to the particular radiation exposure cycle chosen and the relocation of the α-particle absorbers in the new sampling head design as compared with the CEA design.

Key words: Personal dosimeters; Radon progeny; Thoron progeny; Radiation exposure; Track-etch.

*Research Scientist and Radiation/Respirable Dust/Ventilation Project Leader, Elliot Lake Laboratory, CANMET, Energy, Mines and Resources Canada, Elliot Lake, Ontario.

ÉVALUATION DE DEUX ÉCHANTILLONNEURS, SOIT CLASSIQUE ET MODIFIÉ, MUNIS DE DÉTECTEURS TRACK ETCH, SENSIBLES AUX PARTICULES ALPHA, DANS DES ATMOSPHÈRES CONTENANT DES DESCENDANTS DU RADON/THORON

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J. Bigu*

RÉSUMÉ

Deux modèles d'échantillonneurs sensibles à la particule alpha ont été évalués dans des atmosphères contenant des descendants du radon et du thoron à l'installation expérimentale radon/thoron. Les échantillonneurs sont intégrés à un dosimètre personnel, sensible à la particule alpha, doté d'un détecteur Track Etch mis au point par le CEA (France). On a comparé la performance de l'échantillonneur classique doté d'un détecteur Track Etch de CEA à celle d'un échantillonneur modifié, développé par l'Institut canadien de radioprotection (CAIRS). Dans les conditions d'essai qui prévalaient, la concordance des données sur l'exposition au rayonnement mesurée au moyen de dosimètres et par échantillonnage au hasard peut varier de médiocre à bonne dans des atmosphères qui contiennent des descendants du radon. Dans des atmosphères qui contiennent des descendants du thoron, les données sur l'irradiation dérivées par les techniques de dosimétrie et d'échantillonnage au hasard étaient très différentes. Dans les atmosphères comportant des concentrations de descendants du thoron, on a observé des différences quantitatives quant à la performance de l'échantillonneur développé par l'Institut canadien de radioprotection et à celle de l'échantillonneur mis au point par CEA. Ces différences peuvent découler du choix du cycle particulier d'exposition et de la relocalisation des absorbants de la particule alpha sur le nouvel échantillonneur par rapport à leur position sur l'échantillonneur conçu par CEA.

Mots-clé : Dosimètres personnels; descendants du radon; descendants du thoron; exposition au rayonnement (irradiation); détecteur Track Etch.

*Chercheur scientifique et Chef de projet, Rayonnement/Poussière inhalable/Ventilation, Laboratoire de recherche d'Elliot Lake, CANMET, Énergie, Mines et Ressources Canada, Elliot Lake (Ontario)

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INTRODUCTION

Personal radiation dosimeters have been developed to estimate the exposure of occupational workers to different kinds of radiation.

A number of personal α-particle dosimeters have been designed to evaluate the exposure to α-particle radiation of underground uranium miners and uranium mill workers. Personal α-particle dosimeters are time-integrating devices that can be of the active kind or the passive type. These dosimeters are usually calibrated in terms of α-particle exposure, e.g., Working Level Month (WLM), or Working Level Hour (WLH).

A personal α-particle dosimeter of the active type consists essentially of a low-power consumption, mechanically reliable, sampling pump, and a sampling head housing a filter facing an α-particle detector. Air flows through the filter where the radon and thoron progeny are deposited. Alpha-particles emitted by the α-particle emitters ^{218}Po, ^{214}Po, ^{212}Bi and ^{212}Po are detected by an appropriate detector, e.g., a thermoluminescent detector (TLD), a track-etch detector (e.g., cellulose nitrate LR-115 and CR-39), or a silicon-diffused, surface-barrier or DRAM (Dynamic Random Access Memory) detector.

A variety of radon progeny personal dosimeters have been designed and laboratory and field tested in the U.S.A., Canada and other countries (1-9). CANMET has played a very substantial role in instrument development and the laboratory and field evaluation of this instrumentation (10-19).

This report presents data on a radon/thoron progeny personal dosimeter of the active type using track-etch technology. The performance of two sets of dosimeters with somewhat different sampling head design was compared. The instruments were tested under laboratory controlled conditions in a Radon/Thoron Test Facility (RTTF). The response of the dosimeters was

evaluated using radon/radon progeny only atmospheres and thoron/thoron progeny only atmospheres in the RTTF. This investigation was requested by Dr. E. Becker (Canadian Institute for Radiation Safety (CAIRS)). The dosimeters tested have been designed by the CEA (France). The sampling head modification in some of the dosimeters were implemented by CAIRS.

DESCRIPTION OF THE CEA TRACK-ETCH DOSIMETER

The dosimeter consists of a quasi-cylindrically shaped plastic body where a sampling head and a sampling pump of the turbine type are located. The pump is driven by rechargeable batteries that provide electrical power for about 18 h. The batteries are charged in specially designed racks by magnetic induction.

The sampling head includes a filter holder with an 0.8μm Millipore filter facing a track-etch detector film. The filter and track-etch detector are separated by three collimators which expose three different areas of the track-etch film to the filter. The exposed areas of the track-etch material are covered with three different thicknesses of an α-absorber, i.e., polycarbonate material, to detect α-particles of different energy from radon and thoron progeny sampled in the filter.

Detection of α-particles is done by cellulose nitrate film (Kodak Pathe LR115), the track-etch detector. The sensitive layer of the film is 13 μm thick and red, and is mounted in a colourless Mylar film.

The passage of α-particles through the cellulose nitrate affects the structure of the substance in such a way that if the energy of the incident particle is properly chosen, and appropriate chemical etching is applied, holes of regular dimensions in the detector with diameters of several μm are produced. Detection of radon and thoron progeny α-emitters are effected by polycarbonate absorbers of different thicknesses placed on the detectors as

follows.

The distance covered by the α-particles in the air and the thickness of the absorber is such that at the end of a collimator the α-particles emitted by ^{218}Po (RaA) and ^{214}Po (RaC') do not emerge from the absorber, whereas those emitted by ^{212}Po (ThC') emerge with a residual energy of about 3 MeV and are thus recorded. At the end of the second collimator the α-particles emitted by ^{214}Po emerge with a residual energy of 3 MeV and are recorded, whereas α-particles from ^{218}Po (above 5 MeV) do not leave any tracks with present etching conditions. At the end of the third collimator, α-particles emitted by ^{214}Po and ^{212}Po have energies greater than 5.3 MeV and do not give tracks in the detector film, whereas α-particles from ^{218}Po emerge with an energy of 2.8 MeV and are recorded.

Tracks produced in the detector appear as luminous white patches on a red background. Tracks can be counted using an optical microscope, a spark detector, or by evaluating the density of tracks through the quantity of light transmitted by these holes.

The number of tracks on each area of the track-etch film is related to the respective radionuclide decay rate, and hence to its airborne activity concentration. Track counting, therefore, allows evaluation of the radon and thoron progeny concentrations, and of the Working Levels. As indicated below, track counting also permits the calculation of radiation exposure.

Figure 1 shows a view of the dosimeter and its components. Figure 2 shows details of the components of the sampling head. Both figures describe the components and configuration of the latest version of the CEA track-etch dosimeter. Figure 3 shows, in a highly schematic form, the changes introduced in the CEA dosimeter head. The major changes include the relocation of the absorbers, some modification in the sampling head train, and the substitution of metal (CEA version) by plastic materials (CAIRS design). The reasons for

the design changes can be found elsewhere (16,17,20). The energy of α-particles after traversing 22 cm of air and the dosimeter absorbers is shown in Table 1 (21).

CALCULATION OF RADIATION LEVELS AND RADIATION EXPOSURE

In this report the term radiation level is loosely employed to indicate radon and thoron activity concentrations, or Working Levels. More specifically, however, progeny activity concentrations (pCi/L or mBq/m^3) are indicated by square brackets, i.e., [^{218}Po], whereas Working Levels are indicated either by WL(Rn), radon progeny Working Level, or WL(Tn), thoron progeny Working Level. When no specific reference to WL(Rn) or WL(Tn) is meant, the Working Level is simply referred to as WL. For other special cases, other terminologies are used.

Radiation exposure is measured in Working Level Hours (WLH), or more preferably, in Working Level Months (WLM). The relationship between WLM and WLH is a simple one, namely:

$$WLM = WLH/170 \qquad \text{Eq 1}$$

where,

$$WLH = WL \times T_{exp} \qquad \text{Eq 2}$$

T_{exp} is the exposure time and is given in hours (h). The numerical coefficient 170 represents the average number of working hours in a month.

A. TRACK-ETCH DOSIMETER

Radiation exposure is calculated from experimental data by the dosimeter as follows:

$$WLM(Rn) = \frac{7.7\ N(^{214}Po) \times 5.99\ [N(^{218}Po) - 1/2\ N(^{212}Po)]}{1.06 \times 10^{-3} \times 170 \times 1.3 \times 10^{5} \times Q}$$

$$= 0.4269 \times 10^{-4} \left\{ \frac{7.7\ N(^{214}Po) + 5.99\ [N(^{218}Po) - 0.5\ N(^{212}Po)]}{Q} \right\} \qquad \text{Eq 3}$$

where, $N(^{218}Po)$, $N(^{214}Po)$ and $N(^{212}Po)$ are the number of tracks measured in

the detector above the appropriate absorber. The numerical coefficient 1.06 x 10^{-3} is the overall efficiency of the system. The number 1.3 x 10^{5} represents (in MeV) the total potential α-particle energy from the short-lived progeny in a litre (L) of air at WL = 1. The symbol Q is the sampling flow rate of the dosimeter given in Lh^{-1}. The symbol Rn in WLM is used to indicate radon progeny, hence WLM(Rn) indicates radon progeny exposure in Working Level Month.

Similarly, for the thoron progeny, WLM(Tn) is given:

$$WLM(Tn) = 0.4269 \times 10^{-4}\left(\frac{11.74\ N(^{212}Po)}{Q}\right) = 5.012 \times 10^{-4}\ N(^{212}Po)/Q] \quad \text{Eq 4}$$

It should be noted that for precise calculation of WLM(Rn) and WLM(Tn), the contribution from long-lived radionuclides, if any, should be taken into consideration. This contribution arises from contamination in the sampling heads by long-lived radioactive dust (LLRD). The contribution to the number of tracks from LLRD contamination poses a limit to the accuracy with which WLM(Rn) and WLM(Tn) can be determined (16,17,20-22).

B. GRAB-SAMPLING MEASUREMENTS IN THE RTTF

Radon progeny radioactivity measurements in the RTTF were carried out by the Thomas-Tsivoglou method (23), whereas thoron progeny radioactivity measurements were made using a two gross α-count method developed at the Elliot Lake Laboratory and described elsewhere (24).

Radiation exposures from grab-samples were determined using Equations 1 and 2.

EXPERIMENTAL PROCEDURE

The dosimeters were placed at a convenient location in the RTTF and exposed for different periods of time. Daily exposure of the dosimeters ranged between 5 h to 8 h. The total duration of the evaluation was 12 days.

Evaluation in radon/radon progeny only atmospheres was conducted over a period of 6 days. A total of 8 dosimeters was used in the evaluation, of which 4 were modified by CAIRS. Two evaluations lasting 3 days each, using 4 dosimeters at a time, were conducted.

Evaluation of the dosimeters in thoron/thoron progeny only atmospheres was carried out for a total of 6 days. Two evaluations lasting 2 days and 4 days were made using 4 dosimeters each time, i.e., a total of 8 dosimeters was involved, of which, as before, 4 had been modified by CAIRS.

Two different radon progeny concentration atmospheres were used for exposure purposes. The first test was conducted at low aerosol concentration (~1.0 x 10^3 cm^{-3}) in order to maintain WL(Rn) at a low level, i.e., WL ~0.03 - 0.04. The second test was carried out at higher aerosol concentration (~1.0 x 10^4 cm^{-3}) resulting in a WL(Rn) ranging from 0.17 to 0.22. In the case of thoron progeny atmospheres the aerosol concentration was in the range 8.0 x 10^3 to 1.5 x 10^4 cm^{-3} resulting in values for the WL(Tn) from about 7.5 to 14. WL(Rn) and WL(Tn) were purposely varied from day to day to better investigate the performance of the dosimeters under dynamic situations.

After exposure in the RTTF, the dosimeters were sent to CAIRS for chemical track-etching and track-etch counting. The latter was then used to estimate WLM for the radon progeny atmosphere and thoron progeny atmosphere according to Equations 3 and 4, respectively.

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental data obtained have been summarized in Tables 2 to 8. Tables 2 and 3 show radon progeny data in the RTTF corresponding to the first dosimeter's exposure and second dosimeter's exposure, respectively. The first exposure (Table 2, Sept. 17, 18, 21/87) was done at low aerosol concentration

($\lesssim 1.0 \times 10^3$ cm^{-3}), and hence, at low radiation levels ($\overline{WL}$ ~0.3 - 0.4), and low disequilibrium ratios ([^{214}Pb]/[^{218}Po] ~0.11), ([^{214}Bi]/[^{218}Po] ~0.08). The second exposure (Table 3, Sept. 22-24/87) was conducted at substantially higher aerosol concentrations (8.0×10^3 - 1.5×10^4 cm^{-3}), and hence significantly higher radiation levels ($\overline{WL}$ ~0.17 - 0.23), and higher disequilibrium ratios ([^{214}Pb]/[^{218}Po] ~0.47, [^{214}Bi]/[^{218}Po] ~0.3). (Note: the horizontal bar on top of WL is used to indicate daily average value. The low disequilibrium ratios at low aerosol concentrations are due to radon progeny plate-out on the RTTF walls.)

Table 4 shows thoron progeny data in the RTTF corresponding to the exposure of the dosimeters during July 30-31/87 (first exposure), and August 10, 11, 14, 18/87 (second exposure). Dosimeters were exposed at aerosol concentrations in the range 8.0×10^3 - 1.5×10^4 cm^{-3}, and WL(Tn) ~7.5 - 14.5. The thoron progeny disequilibrium ratio [^{212}Bi]/[^{212}Pb] was in the range 0.4 to 0.5.

Tables 5 and 6 present dosimeter and RTTF data corresponding to the first and second radon progeny exposures, respectively. Tables 5 and 6 complement (and should be read in conjunction with) Tables 2 and 3, respectively. Table 5 shows substantial discrepancies between dosimeter data, mWLM(Rn)$_D$, and grab-sampling data, mWLM(Rn)$_{RTTF}$. The discrepancies are attributed to plate-out of radon progeny in the dosimeter's sampling head at low aerosol concentration, contamination, and to poor statistics of counting, i.e., few tracks available for counting. Because of the above, sensitivity and performance differences between the 'old' sampling head (CEA) and the new design (CAIRS/CEA) cannot be ascertained from these data.

The data of Table 6 show that there is a very significant improvement in the performance of the dosimeters at higher radon progeny Working Levels

(see Table 5). Agreement between $mWLM(Rn)_D$ and $mWLM(Rn)_{RTTF}$, and between the CEA design and CAIRS/CEA design can be considered reasonably good.

Tables 7 and 8 show dosimeter and RTTF data corresponding to the first and second thoron progeny exposures, respectively. Exposure conditions in both cases were nearly identical, only total exposure was different. Substantial disagreement between $mWLM(Tn)_D$ and $mWLM(Tn)_{RTTF}$ can be observed, i.e., the dosimeter underestimated thoron progeny exposure by 14-60%. The reasons for this disagreement are not clear. Since counting statistics were quite good at this radiation level (WL(Tn) ~7.5 - 14.5), the discrepancies found could arguably be attributed to the particular exposure cycle of the experiment and the short daily exposure times used. Tables 7 and 8 also show that the CAIRS/CEA sampling head design seems to be 12-20% more sensitive to thoron progeny exposure than the CEA design. This observation should be verified by further testing. No such effect could be ascertained under radon progeny exposure, most likely because of poor statistics of counting. The effect noted above may have to do, if confirmed, with the arrangement of the α-particle absorbers in the CAIRS/CEA design (see Figure 3).

CONCLUSIONS

Poor agreement was found between $mWLM(Rn)_D$ and $mWLM(Rn)_{RTTF}$ for low radon progeny exposures. The agreement improved considerably for higher exposures to radon progeny atmospheres. For thoron progeny exposures agreement between the dosimeters and grab-sampling was poor. The dosimeters were found to underestimate (14-60%) thoron progeny exposures as compared with calculations from RTTF grab-sampling data.

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Table 1 - Energy of α-particles after traversing 22 cm of air and the dosimeter absorbers (21).

Absorber Thickness	ALPHA ENERGIES AT DETECTOR					
	^{218}Po		^{214}Po		^{212}Po	
	Absorber Up	Absorber Down	Absorber Up	Absorber Down	Absorber Up	Absorber Down
8 μm	2.72(2.7)	2.67(2.65)	(5.1)	-	(6.1)	-
25 μm	0	0	3.1(3.1)	3.0(3.1)	(4.6)	-
36 μm	0	0	(0.25)	(0.1)	3.2(3.2)	3.3(3.3)

Notes: 1) Value in parentheses is the calculated value. The other values were measured experimentally.

2) Absorber Up is the present CEA design. Absorber Down is the proposed CAIRS-CEA design.

Table 2 - Radon progeny data by the Thomas-Tsivoglou method measured in the RTTF.

Date	Time	WL(Rn)	$[^{218}Po]$ pCi/L	$[^{214}Pb]$ pCi/L	$[^{214}Bi]$ pCi/L	$\frac{[^{214}Pb]}{[^{218}Po]}$	$\frac{[^{214}Bi]}{[^{218}Po]}$
Sept 17/87	8:38	0.030	14.38	1.63	1.97	0.11	0.14
"	9:49	0.033	17.05	1.87	1.59	0.11	0.09
"	10:46	0.036	18.58	2.11	1.57	0.11	0.08
"	11:33	0.034	16.92	2.32	1.18	0.14	0.07
"	12:37	0.041	21.18	2.86	1.35	0.14	0.06
"	13:31	0.047	24.68	2.89	1.82	0.12	0.07
"	14:30	0.058	26.95	4.45	1.97	0.17	0.07
"	15:23	0.066	28.08	5.45	2.61	0.19	0.09
Average:		0.043±0.013	20.98±5.01	2.95±1.34	1.76±0.44	0.14±0.03	0.08±0.03
Sept 18/87	8:30	0.032	17.68	2.21	0.67	0.13	0.04
"	9:30	0.029	14.97	1.30	1.77	0.09	0.12
"	10:30	0.029*	-	-	-	-	-
"	11:30	0.036	20.89	2.41	0.65	0.12	0.03
"	12:35	0.035	18.40	2.20	1.26	0.12	0.07
"	13:30	0.033	17.86	1.84	1.31	0.10	0.07
"	14:30	0.031	16.26	1.49	1.75	0.09	0.11
"	15:30	0.038	23.69	2.66	-	0.11	-
Average:		0.033±0.003	18.5±2.92	2.02±0.49	1.24±0.49	0.11±0.02	0.07±0.04
Sept 21/87	8.07	0.027	14.68	1.72	0.79	0.12	0.05
"	9.21	0.027	16.21	1.71	0.50	0.11	0.03
"	10:31	0.025	15.23	1.52	0.38	0.10	0.02
"	11:32	0.028	17.04	1.83	0.31	0.11	0.02
"	12:33	0.021*	-	-	-	-	-
"	13:32	0.039	21.45	3.11	0.12	0.14	0.01
"	14:33	0.040	21.75	2.90	0.82	0.13	0.04
"	15:27	0.031	17.04	1.96	1.04	0.12	0.06
Average:		0.030±0.007	17.6±2.85	2.11±0.63	0.57±0.33	0.12±0.01	0.03±0.02

Note: * Measurement by the Kusnetz method (25).

Table 3 - Radon progeny data by the Thomas-Tsivoglou method measured in the RTTF.

Date	Time	WL(Rn)	$[^{218}Po]$ pCi/L	$[^{214}Pb]$ pCi/L	$[^{214}Bi]$ pCi/L	$\frac{[^{214}Pb]}{[^{218}Po]}$	$\frac{[^{214}Bi]}{[^{218}Po]}$
Sept 22/87	9:36	0.149	37.51	15.09	9.17	0.40	0.24
"	10:27	0.155	35.05	15.82	10.42	0.45	0.30
"	11:26	0.148	36.17	14.09	10.46	0.39	0.29
"	12:32	0.141	27.56	13.31	11.93	0.48	0.43
"	13:28	0.167	34.23	16.48	12.93	0.48	0.38
"	14:33	0.214	44.98	22.52	14.18	0.50	0.32
"	15.25	0.244	54.41	24.50	17.01	0.45	0.31
Average:		0.174±0.04	38.56±8.67	17.4±4.34	12.3±2.68	0.45±0.04	0.32±0.06
Sept 23/87	8:32	0.092	31.10	9.26	3.55	0.30	0.11
"	9:22	0.135	36.89	13.64	7.37	0.37	0.20
"	10:22	0.154	36.96	14.62	11.20	0.40	0.30
"	11:22	0.184	39.97	18.36	13.26	0.46	0.33
"	12:24	0.204	44.63	21.00	13.88	0.47	0.31
"	13:22	0.213	48.47	21.00	15.26	0.43	0.31
"	14:20	0.231	43.11	24.23	17.02	0.56	0.39
"	15:20	0.246	48.97	25.56	17.69	0.52	0.36
Average:		0.195±0.04	41.3±6.2	18.5±5.6	12.4±4.9	0.44±0.08	0.29±0.09
Sept 24/87	8:24	0.075	32.76	6.64	2.04	0.20	0.06
"	9:18	0.141	33.02	14.33	9.09	0.43	0.28
"	10:33	0.186	42.50	18.87	12.46	0.44	0.29
"	11:15	0.192	40.78	18.30	15.19	0.45	0.39
"	12:38	0.221	48.77	22.41	15.38	0.46	0.31
"	13:24	0.228	44.44	21.99	18.88	0.49	0.42
"	14:22	0.256	53:28	25.60	19.14	0.48	0.36
"	15:27	0.270	60.57	28.22	17.27	0.47	0.28
Average:		0.226±0.034	44.5±9.6	19.5±6.8	13.68±5.76	0.43±0.09	0.30±0.11

Table 4 - Thoron progeny data measured in the RTTF (24)

Date	Time	$[^{212}Pb]$	$[^{212}Bi]$	$\frac{[^{212}Bi]}{[^{212}Pb]}$	WL(Tn)	$\overline{WL(Tn)}$*
July 30/87	10:00	81.94	35.27	0.43	10.54	11.32
	13:25	93.63	44.29	0.47	12.10	
July 31/87	9:47	56.12	21.76	0.39	7.19	7.70
	13:24	64.10	25.90	0.40	8.22	
Aug. 10/87	12:00	111.93	53.80	0.48	14.47	14.62
	14:04	114.08	56.54	0.49	14.77	
Aug. 11/87	11:34	87.44	44.23	0.51	11.33	11.48
	13:37	89.94	43.69	0.49	11.63	
Aug. 14/87	11:00	91.57	41.40	0.45	11.80	11.76
	13:00	91.00	40.31	0.44	11.72	
Aug. 18/87	12:00	72.05	29.40	0.41	9.25	9.44
	14:00	75.00	31.30	0.42	9.64	
Average:		85.73±17.3	38.99±10.64	0.45±0.04	11.06±2.27	11.05±2.34

*Note: the horizontal bar is used to indicate daily average.

Table 5 - Personal dosimeter exposure data and radon progeny exposure levels in the Radon/Thoron Test Facility (RTTF) (Sept 17, 18 and 21/87 test).

Dosimeter No.	$\bar{Q}$ (L/h)	$N(^{218}Po)$ (tracks)	$N(^{214}Po)$ (tracks)	$N(^{212}Po)$ (tracks)	$mWLM(Rn)_D$	$mWLM(Rn)_{RTTF}$	Remarks
2299	5.12	19	51	17 (0)	4 (4)	4.41	CEA
2300	5.50	0	41	10 (0)	2 (2)	4.41	CEA
5	6.09	32	193	224 (0)	7 (12)	4.41	CAIRS/CEA
6	5.29	19	62	22 (0)	4 (5)	4.41	CAIRS/CEA

Notes:

1. $\bar{Q}$ stands for average dosimeter flow rate.
2. 1 mWLM = 1.0×10^{-3} WLM.
3. The symbol (Rn) is used to indicate radon progeny.
4. The subindices D and RTTF are used to indicate: as obtained by the dosimeter and in the RTTF, respectively.
5. CEA refers to 'old' sampling head design. CAIRS/CEA refers to the new sampling head design.
6. The values of $mWLM(Rn)_D$ in round brackets have been calculated by setting $N(^{212}Po) = 0$. The values of $mWLM(Rn)_D$, based on the actual experimental values of $N(^{212}Po)$, are shown on the left of the round brackets.
7. The value for $mWLM(Rn)_{RTTF}$ has been calculated from daily average values of WL(Rn), shown in Table 2, dosimeter exposure times (5.57 h for Sept. 17/87, 8.07 h for Sept. 18/87, and 7.75 h for Sept. 21/87). and Equations 1 and 2).
8. The conditions in the RTTF were as follows: aerosol concentration ($N \bar{<} 3 \times 10^3$ cm^{-3}, $[^{214}Pb]/[^{218}Po] \sim 0.11$, $[^{214}Po]/[^{218}Po] \sim 0.08$.

Table 6 - Personal dosimeter exposure data and radon progeny exposure levels in the Radon/Thoron Test Facility (RTTF) (Sept. 23-24/87 test).

Dosimeter No.	$\bar{Q}$ (L/h)	$N(^{218}Po)$ (tracks)	$N(^{214}Po)$ (tracks)	$N(^{218}Po)$ (tracks)	$mWLM(Rn)_D$	$mWLM(Rn)_{RTTF}$	Remarks
2297	5.00	42	327	36 (0)	23 (24)	22.2	CEA
2298	5.76	37	303	53 (0)	18 (19)	22.2	CEA
7	5.05	77	236	43 (0)	18 (19)	22.2	CAIRS/CEA
8	5.16	29	272	24 (0)	18 (19)	22.2	CAIRS/CEA

Notes:
1. $\bar{Q}$ stands for average dosimeter flow rate.
2. 1 mWLM = 1.0×10^{-3} WLM.
3. The symbol (Rn) is used to indicate radon progeny.
4. The subindices D and RTTF are used to indicate: as obtained by the dosimeter and in the RTTF, respectively.
5. CEA refers to 'old' sampling head design. CAIRS/CEA refers to the new sampling head design.
6. The values of $mWLM(Rn)_D$ in round brackets have been calculated by setting $N(^{212}Po) = 0$. The values of $mWLM(Rn)_D$, based on the actual experimental values of $N(^{212}Po)$, are shown on the left of the round brackets.
7. The value for $mWLM(Rn)_{RTTF}$ has been calculated from daily average values of WL(Rn), shown in Table 3, dosimeter exposure times (5.32 h for Sept. 22/87, 6.77 h for Sept. 23/87, and 7.1 h for Sept. 24/87), and Equations 1 and 2.
8. The conditions in the RTTF were as follows: aerosol concentration (N) $\sim 8.0 \times 10^3 - 1.5 \times 10^4$ cm^{-3}, $[^{214}Pb]/[^{218}Po] \sim 0.48$, $[^{214}Po]/[^{218}Po] \sim 0.30$.

Table 7 - Personal dosimeter exposure data and thoron progeny exposure levels in the Radon/Thoron Test Facility (RTTF) (July 30-31/87 test).

Dosimeter No.	$\bar{Q}$ (L/h)	$N(^{212}Bi)$ (tracks)	$N(^{214}Po)$ (tracks)	$N(^{218}Po)$ (tracks)	$mWLM(Tn)_D$	$mWLM(Tn)_{RTTF}$	Remarks
2297	4.59	3461	181	5770	629	855	CEA
2298	4.53	3109	250	5706	632	855	CEA
5	4.54	3976	429	7129	786	855	CAIRS/CEA
6	4.48	3523	159	6460	723	855	CAIRS/CEA

Notes:
1. $\bar{Q}$ stands for average dosimeter flow rate.
2. 1 mWLM = 1.0×10^{-3} WLM.
3. The symbol (Tn) is used to indicate thoron progeny.
4. The subindices D and RTTF are used to indicate: as obtained by the dosimeter and in the RTTF, respectively.
5. CEA refers to 'old' sampling head design. CAIRS/CEA refers to the new sampling head design.
6. The value for $mWLM(Tn)_{RTTF}$ has been calculated from daily average values of WL(Tn), shown in Table 4, dosimeter exposure times (7.63 h for July 30/87 and 7.63 h for July 31/87), and Equations 1 and 2.
7. The conditions in the RTTF were as follows: aerosol concentration $(N) \sim 8.0 \times 10^3 - 1.2 \times 10^4$ cm^{-3}, $[^{212}Bi]/[^{212}Pb] \sim 0.4 - 0.5$.

Table 8 - Personal dosimeter exposure data and thoron progeny exposure levels in the Radon/Thoron Test Facility (RTTF) (Aug. 10, 11, 14, 18/87 test).

Dosimeter No.	$\bar{Q}$ (L/h)	$N(^{212}Bi)$ (tracks)	$N(^{214}Po)$ (tracks)	$N(^{218}Po)$ (tracks)	$mWLM(Tn)_D$	$mWLM(Tn)_{RTTF}$	Remarks
2296	5.30	6679	414	9848	932	1522	CEA
2299	4.62	4938	313	8463	919	1522	CEA
7	4.65	5559	132	10057	1084	1522	CAIRS/CEA
8	4.65	5913	67	9109	982	1522	CAIRS/CEA

Notes:
1. $\bar{Q}$ stands for average dosimeter flow rate.
2. 1 mWLM = 1.0×10^{-3} WLM.
3. The symbol (Tn) is used to indicate thoron progeny.
4. The subindices D and RTTF are used to indicate: as obtained by the dosimeter and in the RTTF, respectively.
5. CEA refers to 'old' sampling head design. CAIRS/CEA refers to the new sampling head design.
6. The value for $mWLM(Tn)_{RTTF}$ has been calculated for daily average values of WL(Tn), shown in Table 4, dosimeter exposure times (5.50 h for Aug. 10/87, 4.88 h for Aug. 11/87, 6.00 h for Aug. 14/87, and 5.50 h for Sept. 18/87), and Equations 1 and 2.
7. The conditions in the RTTF were as follows: aerosol concentration (N) $\sim 1.0 - 1.5 \times 10^4$ cm^{-3}, $[^{212}Bi]/[^{212}Pb] \sim 0.4 - 0.5$.

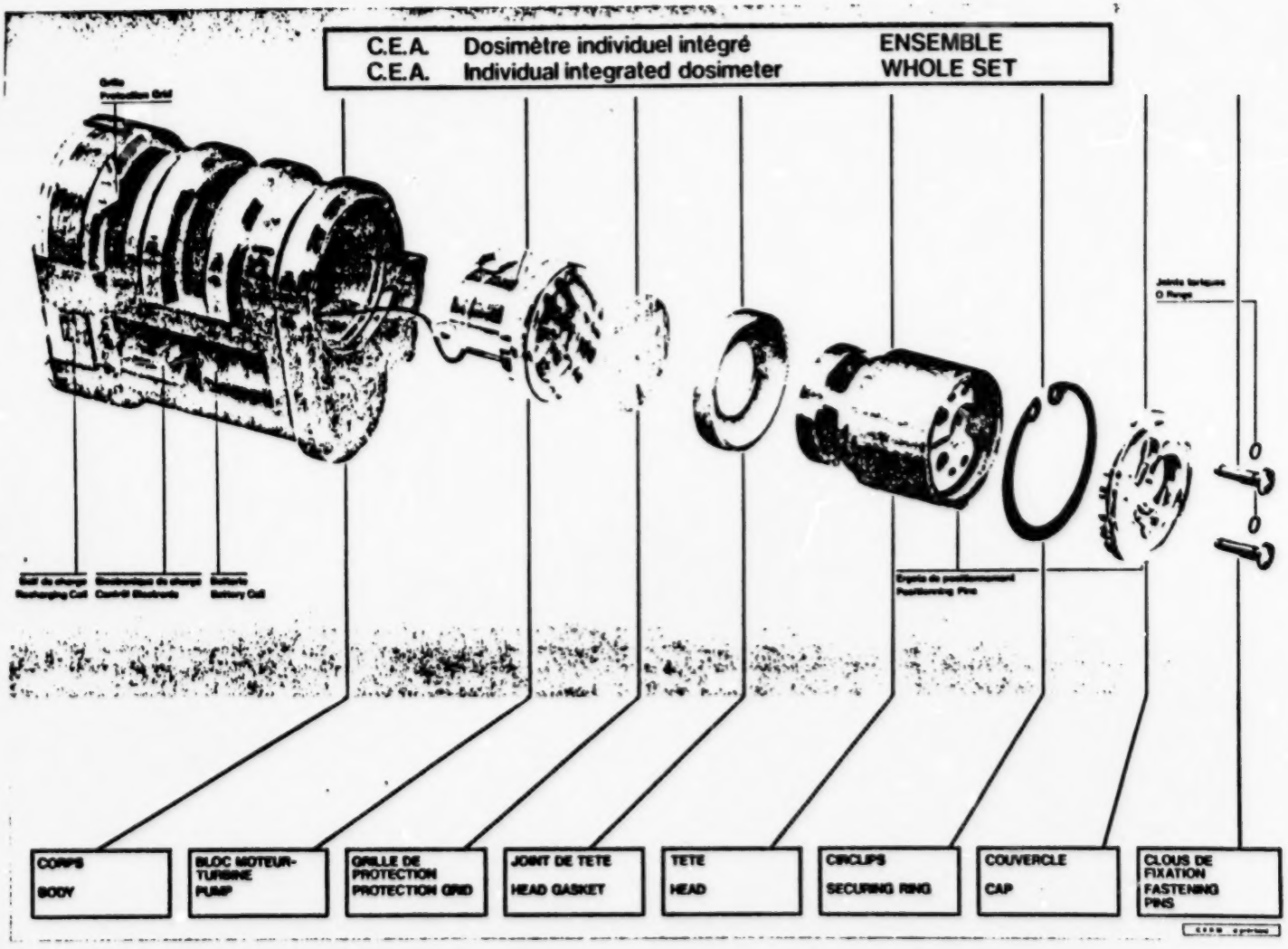

Fig. 1 - View of the CEA track etch dosimeter and components.

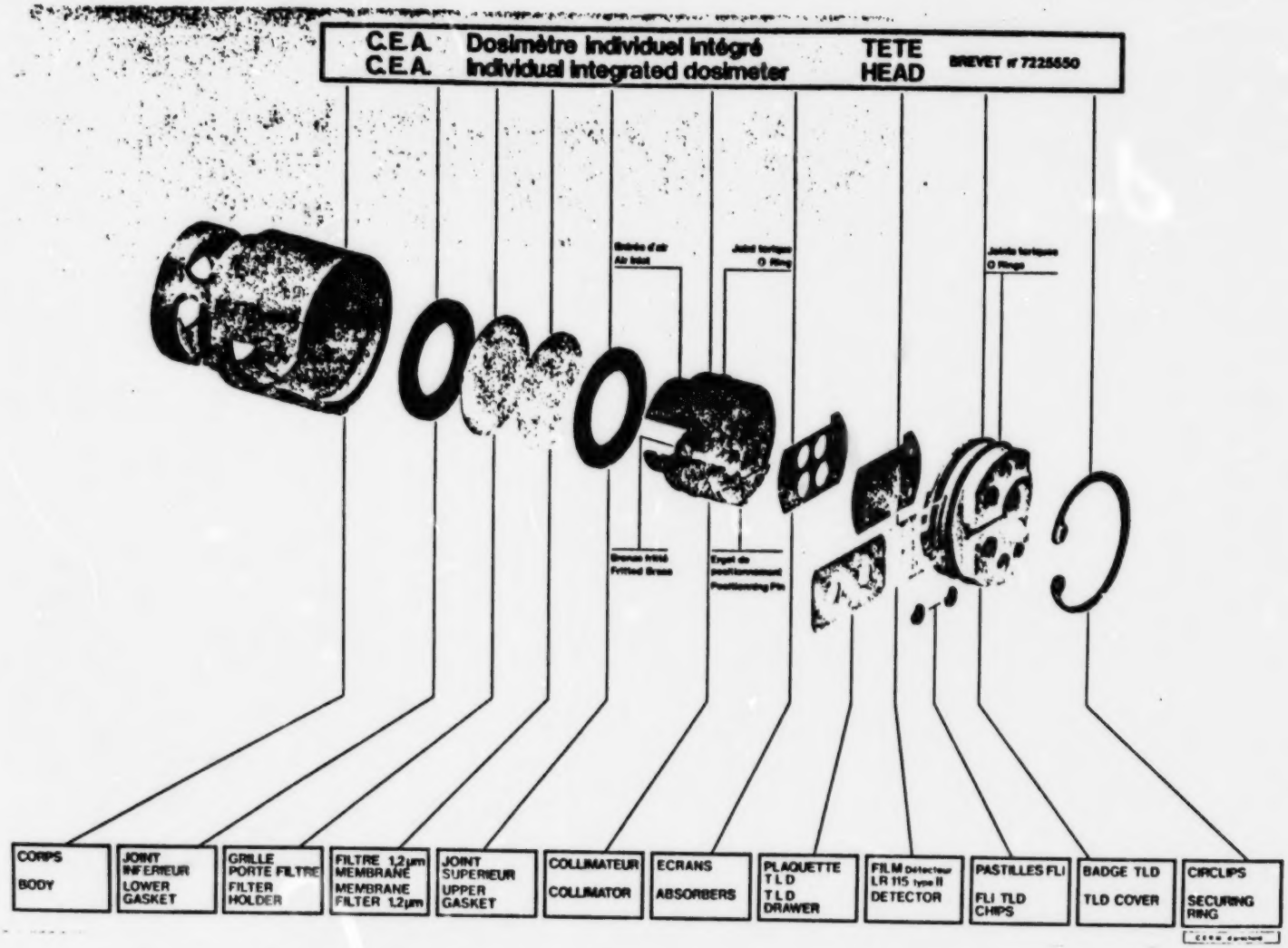

Fig. 2 - Details of CEA track etch dosimeter sampling head.

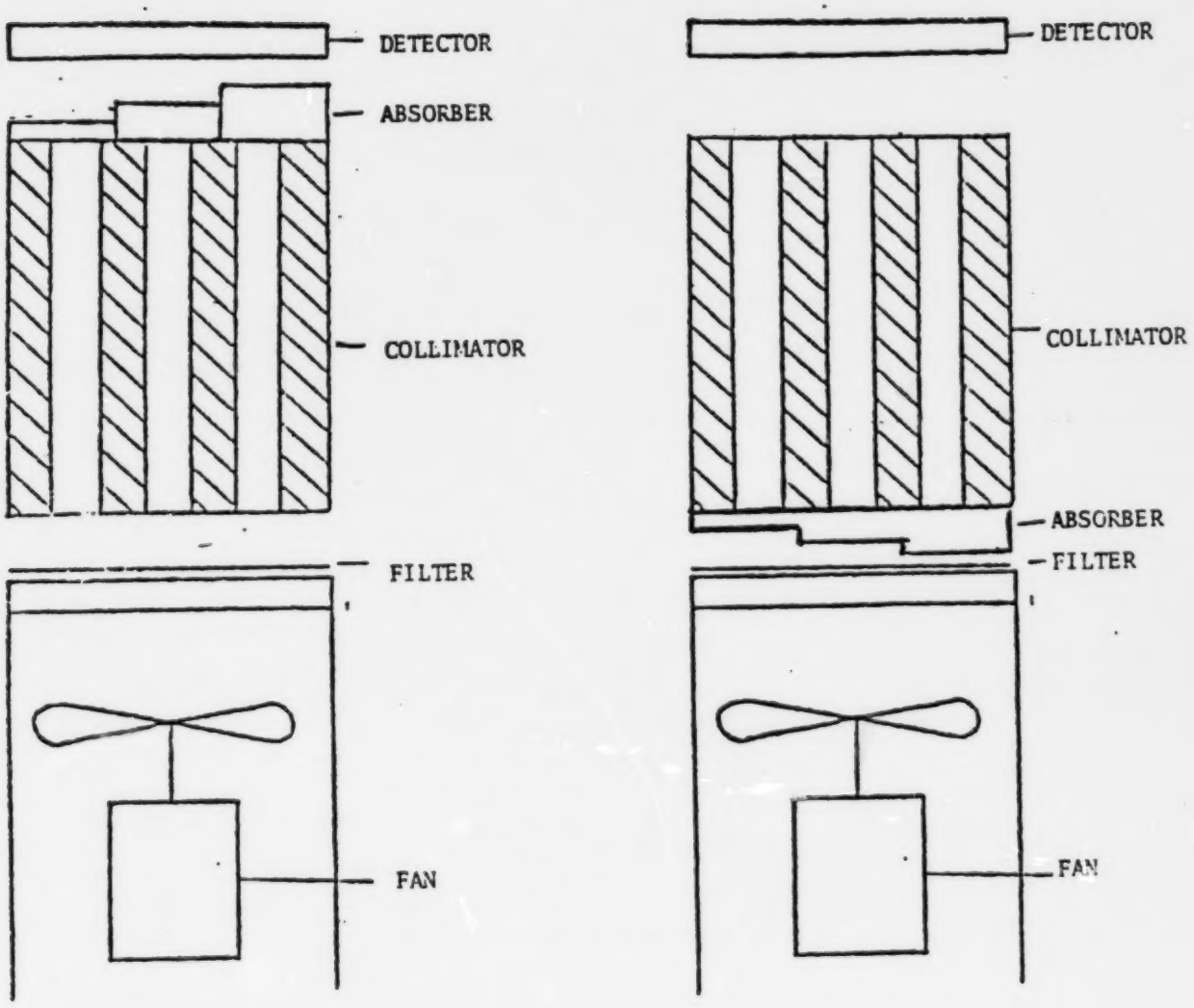

Fig. 3 - Normal CEA dosimeter configuration (left hand side), and modified configuration (right hand side).